Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 195 (2015) 2363 – 2369

Procedia
Social and Behavioral Sciences

World Conference on Technology, Innovation and Entrepreneurship

# An Investigation on The Parameters That Affect The Performance of Hydrogen Fuel Cell

Aysel Ersoy Yilmaz[a]*,Mehmet Murat Ispirli[a]

[a]*Electrical and Electronics Engineering Department, University of İstanbul,İstanbul,34320,Turkey*

**Abstract**

Most of the energy used in the world is obtained from fossil fuels. Some reasons like air and environmental pollution, high-energy costs and depletion of fossil fuels, increased the importance of studies about new and renewable energy sources in the world. Among the new and renewable energy sources hydrogen has great importance. Hydrogen which exists in great amounts in the world has the highest energy content per unit mass. The subject of fuel cells is one of the main research topics in hydrogen energy. The purpose of this study, is to analyze the performance of fuel cells. to do this a model of fuel cell is created in Finite element method program. membrane thickness and electrolyte type of fuel cell is selected as variables.


Peer-review under responsibility of Istanbul Univeristy.

*Keywords:* Fuel Cell,PEM,hydrogen fuel cell;

## 1. Introduction

Studies are being carried out on many alternative methods in order to meet the energy demand required in the place of the fossil fuels that are gradually decreasing throughout the world. One of these methods, the fuel cell directly produces electricity electrochemically from the chemical energy of the fuel. Electrochemical reactions are used in fuel cells as in the traditional batteries. However, fuel cells can produce energy as long as they are fed by the fuel, without the need to be charged. (Ibrahimoglu,2008), (Ultanir, 1998),(Veziroglu & Barbir, 1998)

* Corresponding author. Tel.: +9-0212-473-7070-17905
*E-mail address:* aersoy@istanbul.edu.tr


Peer-review under responsibility of Istanbul Univeristy.
doi:10.1016/j.sbspro.2015.06.204

The main principle of the fuel cell was discovered by the Swedish scientist Christian Schoenbein in 1838. In 1839, Sir William Grove discovered the first fuel cell based on the total opposite principle of the electrolysis of water. In 1950, Francis Bacon introduced the first alkaline fuel cell of 5 kW in the University of Cambridge.(Srinivasan,2006)

The fuel cell module consists mainly of two electrodes (anode and cathode) and the membranes placed between the electrodes. While reactions take place between the fuel and the oxygen in the fuel cell, electric current and heat are formed. Natural gas, methanol or coal gas can also be used as a fuel, as well as pure hydrogen. The main operating principle of the fuel cell is shown in figure-1.

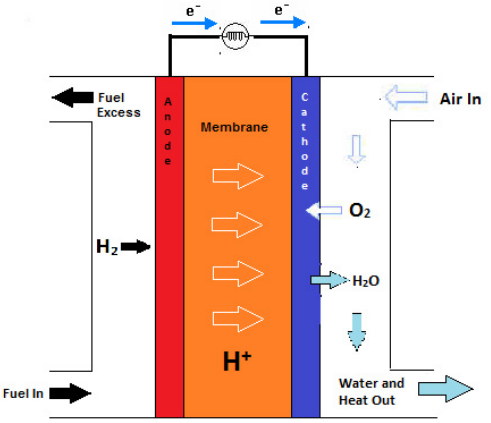


Fig. 1. Basic Proton Exchange Membrane (PEM) Fuel Cell Mechanism

The hydrogen merges with the oxygen in the air in the inner part of the fuel cell and produces electric current; and only water and heat are formed as side products. There is a membrane, which is in contact with the electrodes in both sides, in the middle of the fuel cell. The membrane is constantly fed by hydrogen from the anode and by oxygen from the cathode. Hydrogen is decomposed into positive and negative ions at the anode side. The membrane only lets the positive ions to flow from the anode side to the cathode side, and acts as an insulator for the electrons. The ions reunite at the cathode end for the stability of the system. (Ibrahimoglu,2008),(Srinivasan,2006),(Biyikoglu,2007),(Ameri & Oroojie,2011),(Turkmen,2012),(Ekiz,2010) Free electrons pass to the cathode side by means of an electronic circuit outside the membrane. Positive and negative ions reunite in the cathode and form oxygen and water vapor. The chemical reactions occurring in the anode and cathode are as below.

Anode reaction: $H^2 \rightarrow 2H^+ + 2e^-$
Cathode reaction: $1/2O^2 + 2H^+ + 2e^- \rightarrow H^2O$
Total reaction : $H^2 + 1/2O^2 \rightarrow H^2O$

In this study, the membrane thickness and the conductivity of the electrolyte are chosen for the performance analysis as variable parameters. These two values can be changed during the production stage of the fuel cell and are decisive in fuel cell selection. The change in the parameters was examined by means of the change in the current density values taken from the anode ends. Finite elements method was used in the theoretical modeling of the fuel cell. Comsol Multiphysics program was benefited from in the analyses made using the finite elements method.

## 2.Method

### 2.1.Theoretical Background

The finite elements method was first used in the 1950s in the field of construction engineering.(Wikipedia) Today, it has increased its popularity during the last 20 years, and this method is now preferred in many commercial software. Many devices and situations can be modeled using the finite elements method from medicine to mechanics

and from electricity-electronics to chemical reactions. The main feature of the finite elements method is the necessity to define the start finish limit and surface values appropriately. In finite elements method, the surface of the material is analyzed after dividing into finite parts. In this study, the analyses were made 2 dimensionally. The electrical, physical and chemical laws used while doing this is briefly reminded in this section.
It is necessary to learn the below material features of the fuel cell used to analyze the basic Proton Exchange Membrane (PEM) fuel cell performance.

- Electrode conductivity
- Membrane thickness
- Membrane permeability
- Hydrogen input pressure
- Oxygen input pressure

It is also necessary to know the features of the place where the fuel cell is located, such as temperature and pressure. To that end, the boundary conditions of the model should be defined first. The boundary conditions basically defined for such a PEM work are as below.

- Mass transport equations(Maxwell –Stefan diffusion for reactants, water and nitrogen gas)
- Momentum transport (Darcy's law for the gas flows)

There are 3 parts in the fuel cell modeling using the finite elements method. These are shown on the model in figure-2.

- anode (Ωa)
- proton exchange membrane (Ωm)
- cathode (Ωc)

Gas distributors, a gas inlet ($\partial\Omega_{inlet}$), a gas outlet ($\partial\Omega_{outlet}$) and current collectors ($\partial\Omega_{cc}$) were used in each electrode. Each of the electrodes (gas diffusion layers) is in contact with an interdigitated gas distributor, which has an inlet channel ($\partial\Omega$a,inlet), a current collector ($\partial\Omega$a,cc), and an outlet channel ($\partial\Omega$a,outlet). The same notation is used for the cathode side.)

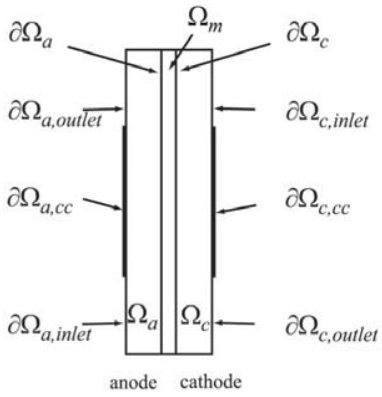


Fig. 2. Model geometry with domain and boundary labels.

**Maxwell–Stefan equations** explain the diffusion phenomena in the multi-component systems in a model. The general form of Maxwell-Stefan equations is as below:

$$\frac{\partial}{\partial t}\rho\omega_i + \nabla\left[-\rho\omega_i\sum_{j=1}^{N} D_{ij}\left\{\frac{M}{M_j}\left(\nabla\omega_j + \omega_j\frac{\nabla M}{M}\right) + (x_j - \omega_j)\frac{\nabla p}{p}\right\} + \omega_i\rho u + D_i^T\frac{\nabla T}{T}\right] = R_i \quad (1)$$

**Darcy law** is a law formulated by Henry Darcy according to the experimental results defining the flow phenomena in porous surfaces. The general form of the equation is as below. In this equation, $k_p$ means the electrode's permeability ($m^2$), η means gas viscosity (Pa*s), and p means pressure(Pa).

$$u = -\frac{k_{ss}}{\eta}\nabla p \tag{2}$$

**Results**

The current density change observed at the anode side of the PEM cell modeled using the finite elements method were examined changing the membrane thickness and electrolyte conductivity. The modeling was performed by means of a commercial program using the finite elements method in the engineering practices, Comsol Multiphysics. Throughout the study, $25^0$C was taken as a reference for the ambient temperature, 1 atm for the ambient pressure, 1.1 atm for the hydrogen input pressure, 1.1 atm for the oxygen input pressure, and 0.7 V for the cell potential. The conductivity value of the electrolyte was used between $0.1x10^3$ and $34000x10^3$. The reason for choosing this range is that this is the range of conductivity values approximately specified for the composite electrodes commercially sold in the market.

The analysis of the finite elements method of the fuel cell model using the laws mentioned above is shown in Figure-3. In this figure, where the model geometry shown in figure-2 is used, it can be seen that the cathode and anode input points are meshed more intensely. The effect of the membrane thickness and electrolyte conductivity on PEM performance was evaluated using the current density values measured at these points.

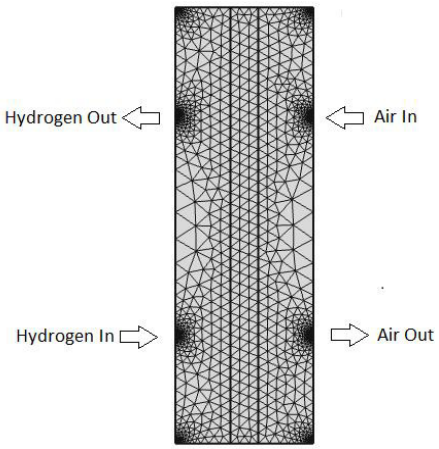


Fig. 3. PEM model after FEM analysis

First of all, the changes of the current density along the y axis for the situations where different types of electrolytes are used were examined in the study. The conductivity of the anodes and cathodes on the model was changed on the PEM models created for this purpose so as to represent different types of electrolytes. The anode and cathode electrodes that are commercially on the market are of a composite structure, and their conductivity is in a variable range and diversity being 1000 S/m or $34x10^6$ S/m.

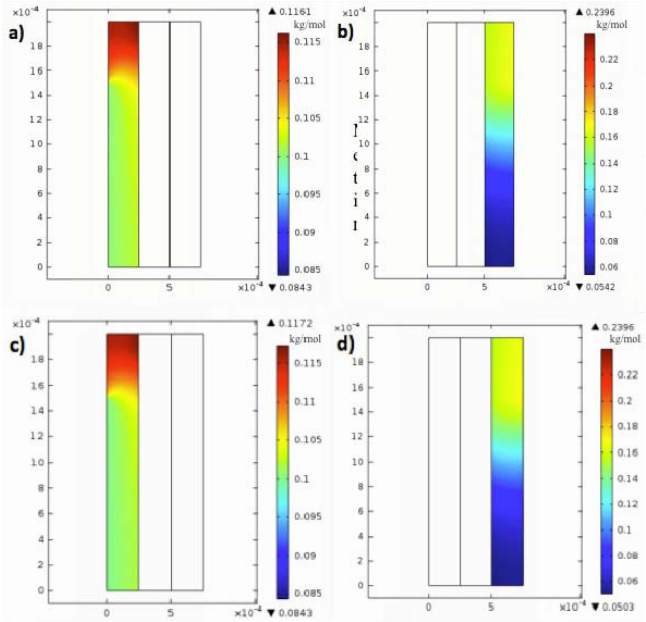


Fig. 4. a) $H_2$ Mass Fraction S=1000 S/m b)$O_2$ Mass Fraction S=1000 S/m
c) $H_2$ Mass Fraction S=14x10$^6$ S/m d)$O_2$ Mass Fraction S=14x10$^6$ S/m

In Figure-4, the change in $H_2$ and $O_2$ mass frictions for two different situations where the conductivity is chosen as 1000 S/m and 14x10$^6$ S/m is shown on the PEM model. For the situation where the conductivity was taken as 1000 S/m, the max $H_2$ mass fraction on the surface was calculated as 0,1161 kg/mol and $O_2$ mass fraction was calculated as 0,2296 kg/mol (Figure 4 a and b). For the situation where the conductivity was taken as 14 x10$^6$ S/m, the max $H_2$ mass fraction on the surface was calculated as 0,1172 kg/mol and $O_2$ mass fraction was calculated as 0,2396 kg/mol (Figure 4 c and d). The points where the maximum values are read for the 2 different values of the conductivity were calculated in the upper part of the anode for $H_2$ mass fraction and the upper external surface of the cathode for $O_2$ mass fraction. Although the conductivity was increased 14 000 times, the change in $H_2$ mass fraction remained limited to 0,9475% and the change in $O_2$ mass fraction remained limited to 4,35%.

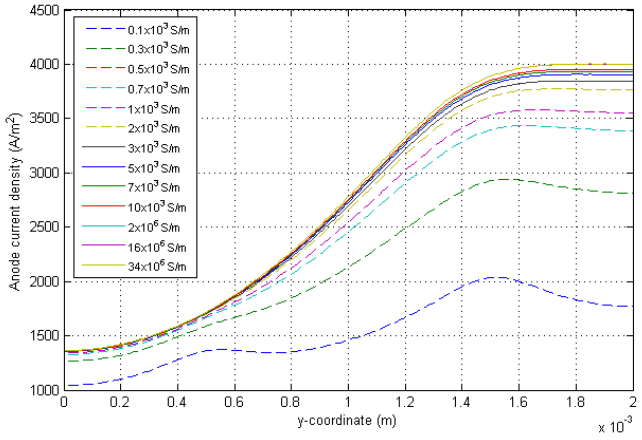


Fig. 5. Change of the anode current density along y axis for the different values of the conductivity

The current density values obtained from the y coordinate (along the surface where the anode surface and the membrane meets) on the PEM model created are shown in figure-5 for different conductivity coefficients. The change of the conductivity and current density varied along the y axis up to 0,1x10$^3$ S/m; 0,3 x10$^3$ S/m; 0,5 x10$^3$ S/m

and 0,7x10$^3$ S/m value of the conductivity. The peak values in $H_2$ input and output points were calculated for the situations where the conductivity is increased up to 700 S/m. The peak values observed in $H_2$ input and output points beyond 1000 S/m value when the conductivity is increased a bit more disappear. The current density values calculated for all of the conductivity values after the conductivity is increased a bit more to 3000 S/m and the calculations are repeated remain almost the same, and the increase in the current density is limited. As is seen in this graph, where the current density calculations are given by changing the conductivity, the current density distinctly increases from the input to the output of $H_2$. Although the value of conductivity increases, the amounts of the oxygen and hydrogen used remain almost the same. As the increase in the conductivity value will decrease the resistive losses, the current density increased quickly up to the value of 2000 S/m. And very little changes were calculated after this value.

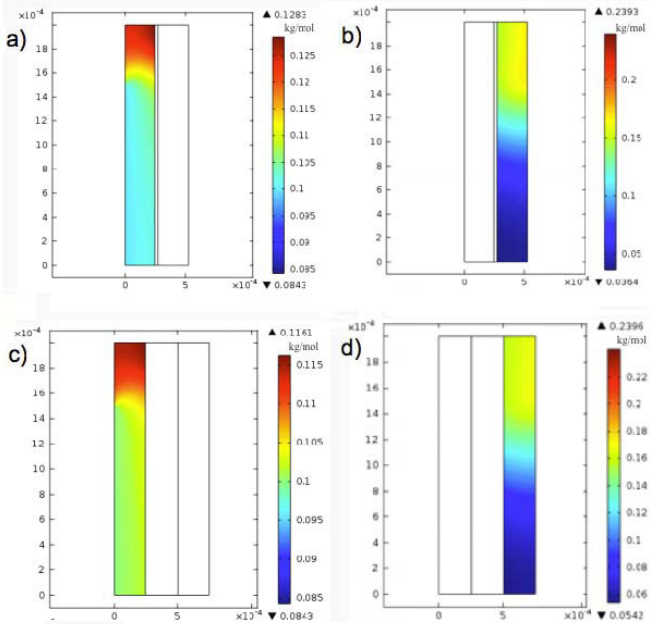


Fig.6. a) $H_2$ Mass Fraction 1mil b)$O_2$ Mass Fraction 1mil
c) $H_2$ Mass Fraction 10 mil d)$O_2$ Mass Fraction 10 mil

Membrane thickness is a parameter that directly affects the electrical performance of PEM cell. While the membrane thickness here determines the $H_2$ density to pass to the cell, it also plays an important role in the calculation of the resistive losses. In Figure-6, the change of the membrane thickness (for 1 mile and 10 miles) and the hydrogen and oxygen mass change are shown along the anode and cathode surfaces. The increase in the membrane thickness decreases the resistive losses created by the membrane. The reacting hydrogen and oxygen amounts change slightly when the thickness is increased. As is also shown here, although the membrane thickness is increased 10 times, the anode and cathode surface distributions of the hydrogen and oxygen are almost the same. While the max mass friction value of $H_2$ is 0.1283 kg/mol at the value where the thickness is 1 mile, the mass friction value of $H_2$ decreased 9.509% to 0.1161 when the thickness is increased 10 times. The max mass friction of the oxygen increased 0.12% to 0.2396 when the thickness was increased 10 times while it was 0.2393 for 1mile. These changes may be neglected upon considering that the membrane thickness increased 10 times. The change in the membrane thickness was chosen between 1 mile and 10 miles. This range was chosen as the membrane thickness values sold commercially in the market varies in this range.

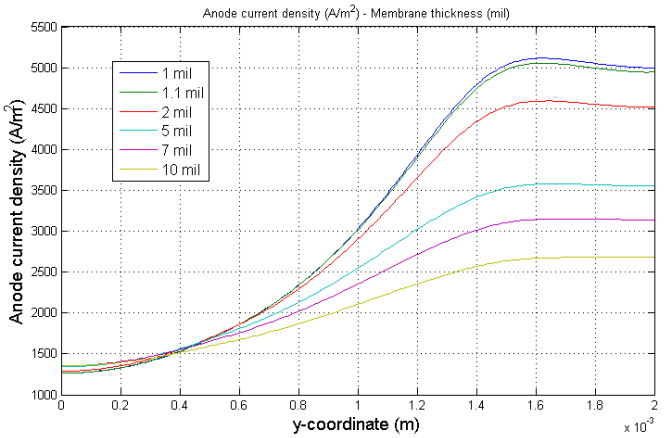


Fig. 7. Change of anode current density along the y axis with the change in the membrane thickness

In Figure-7, the change of the current density of the membranes in 6 different thicknesses from 1 mile to 10 miles along the anode surface is shown. As is also seen in the figure, the current density decreases as the membrane thickness increases. The reason for this decrease is that the membrane resistive losses increases while the $H_2$ and $O_2$ mass fraction values remain nearly the same.

## Conclusion

In this study, data were taken at the temperature of 25°C for 6 different membrane thicknesses and 13 different conductivities from the PEM type fuel cell modeled using the finite elements method 2 dimensionally. As a result of these data;

- According to the thickness of the membrane used; as a result of the calculations made on the model for 6 different values from 1 mile to 10 miles, it was observed that the thickness of 1 mile yields the most productive result based on the current density taken from the anode surface.
- According to the conductivity of the electrolyte used; the value of the current density as a result of the calculations made from 100 S/m to $34x10^6$ S/m remains almost the same after 5000 S/m. The membranes and the electrolytes are pressed to one another at a certain temperature and bonded together. Thus, what is important for an electrolyte to be chosen above a certain value is the corrosion time of the material. Thereby, , a longer cell life may be ensured.
- The membranes and the electrolytes are pressed to one another at a certain temperature and bonded together. Thus, what is important for an electrolyte to be chosen above 5000S/m is the corrosion time of the material. Thereby, a longer cell life may be ensured.

## References

Prof.Dr.Beycan Ibrahimoglu,Hidrojenli Enerji Uretecleri ,2008-194 pages

Prof. Dr. Mustafa Ozcan Ultanir,,21. Yuzyıla Girerken Turkiye'nin Enerji Stratejisinin Degerlendirilmesi. Publication No : TUSIAD-T/98-12/39-12/239 ISBN :975-7249-59-9, Lebib Yalkim Yayimlari ve Basim Isleri AS. Istanbul 1998

Nejat Veziroglu and Bruno Barbir ,Hidrojen Enerji Teknolojileri. Gelismekte Olan Teknoloji Serileri.,Vienna 1998

Supramaniam Srinivasan,Fuel Cells:From Fundamentals to Applications,Chemistry and Materials Science 2005-2008, Springer Science & Business Media,2006,ISBN: 0387251162, 9780387251165

A. Biyikoglu, Review of proton exchange membrane fuel cell models, International Journal of Hydrogen Energy, 30, 2007, pp. 1181-1212.

Mohammad Ameri* , Pooria Oroojie ,Two Dimensional PEM Fuel Cell Modeling at Different Operation Voltages, World Renewable Energy Congress 2011-Linkoping-Sweden

I. Turkmen,2012,PEM tipi yakıt pillerinin iki ve uc boyutlu modellenmesi,*Master Thesis*, TOBB-ETU Institute of Science, Ankara.

Ekiz, A., 2010, PEM Tipi Yakit Pilleri icin Cift Kutuplu Akis Plakalarinin Modellenmesi, *Master Thesis*, TOBB-ETU Institute of Science, Ankara.

http://en.wikipedia.org/wiki/Finite_element_method#History